Beam-beam and compensation schemes: summary and conclusions

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Agenda of the session

1. Summary of the SLAC beam-beam compensation workshop, W. Fischer, BNL
2. Head-on and PACMAN compensation with electron lens, V. Shiltsev, Fermilab
3. Beam-beam and emittance growth with wire compensation, U. Dorda, CERN & U. Vienna
4. Beam-beam and emittance growth with crab cavities, R. Calaga, BNL
5. Beam-beam with a few long-range encounters at short distance, N. Abreu, BNL
6. Beam-beam with long flat bunches and large Piwinski angle, K. Ohmi, KEK

Summary of the SLAC beam-beam compensation workshop, *W. Fischer, BNL*

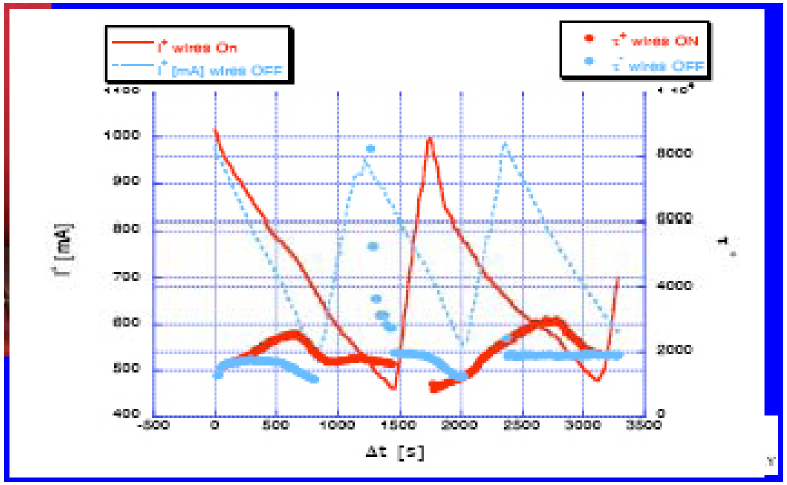
This was an opportunity

- ***to review the phenomenology of the beam-beam "limit" in several machines. This limit shows a "fuzzy regularity". $\Delta Q_{bb,tot}$ (HO) ranges between 0.01 and 0.028. The limit is essentially lifetime (background for early RHIC and ISR). Depending on machine "details", it can be related to LR or HO (TEV). The PACMAN bunches show a reduced lifetime (but no PACMAN effect).***

Summary of the SLAC beam-beam compensation workshop, *W. Fischer, BNL*

This was an opportunity…

• ***to analyze the results obtained in the first attempts of compensation or related studies and their agreement with simulations.***



Wire compensation at Daφne,

C. Milardi

• ***to scrutinize the inconsistencies and analyze (or at least be conscious) of the unexplained observations.***

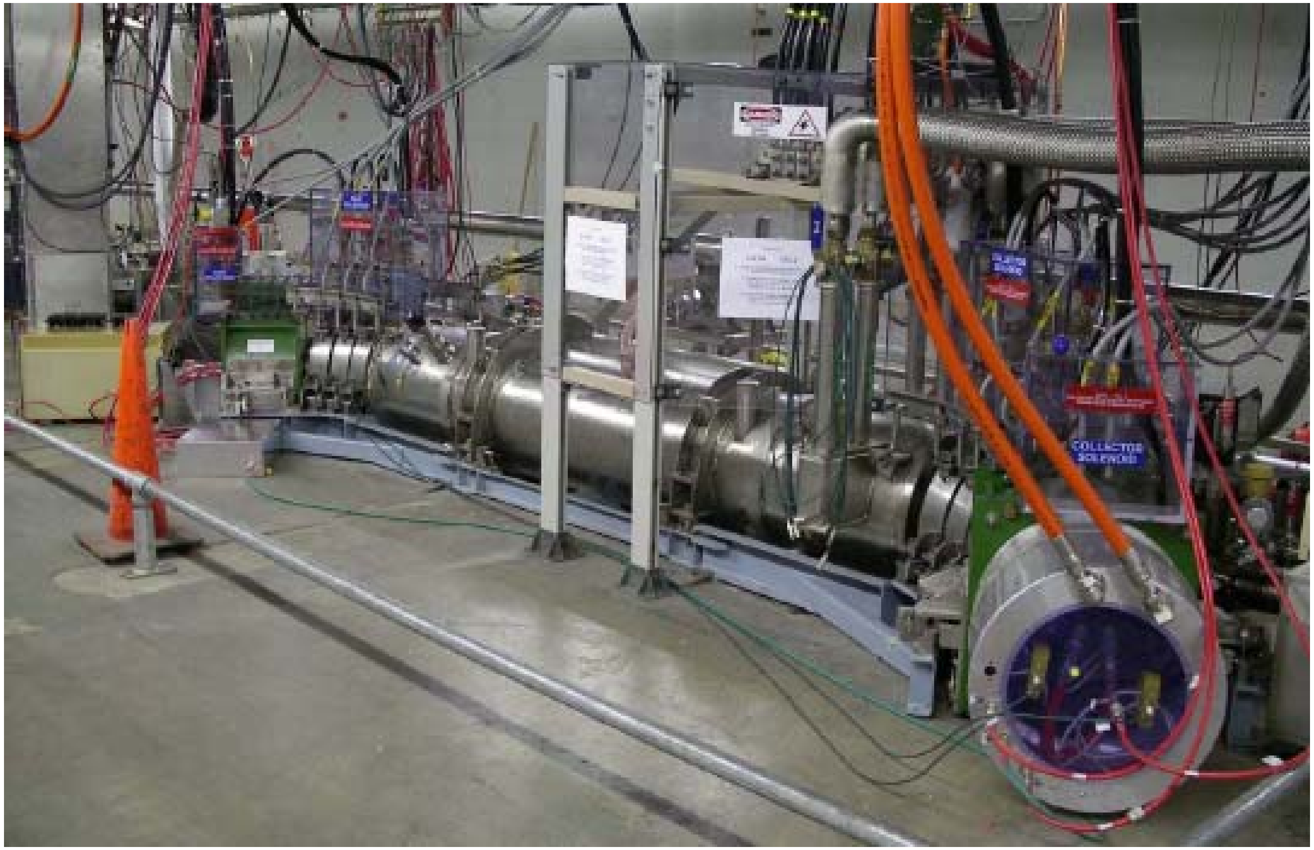
Summary of the SLAC beam-beam compensation workshop, *W. Fischer, BNL*

This was an opportunity…

• ***to share the work, the projects and define experiments (especially at RHIC that appears, with his wire and long beam lifetime, an excellent testbed).***

•***Since then experiments were carried out in the SPS and, hopefully others will be carried out at RHIC (long-range beam-beam effect and compensation) and at TEV (head-on compensation). The relevance of head-on compensation is being studied for RHIC with decision scheduled mid 2008.***

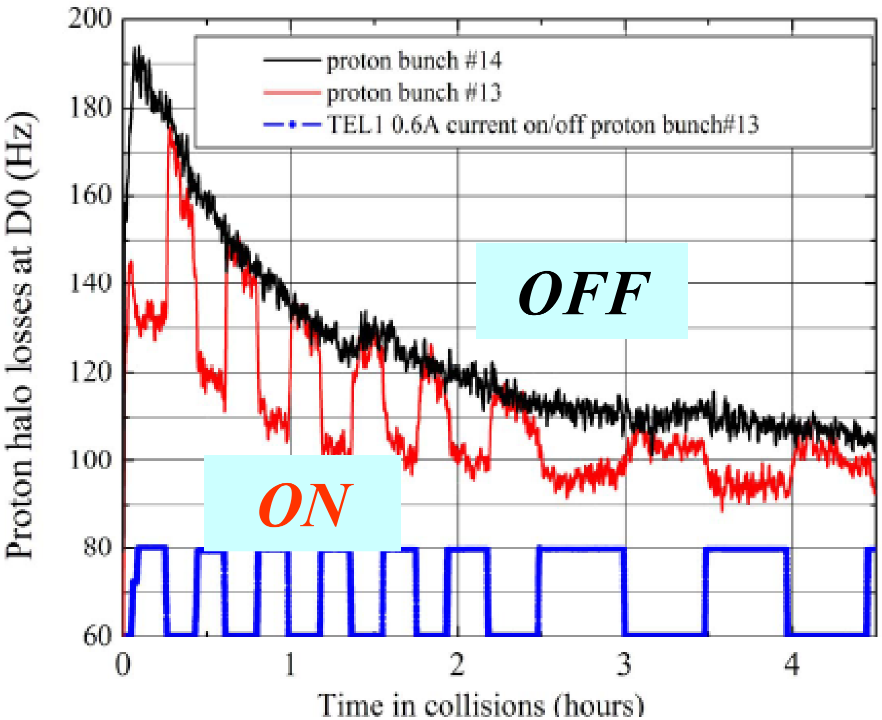
Electron Lenses for compensation of beam-beam effects, *V. Shiltsev, Fermilab*



From speculations ….to implementation

Electron Lenses for compensation of beam-beam effects, *V. Shiltsev, Fermilab*

1. ***Head-on collisions: Used as a linear tune shifter***



- ***equalizing the bunch tunes increases their luminosity lifetimes***
- ***e-lens stable enough not to blow up emittance***
- ***operational use = high reliability shown***

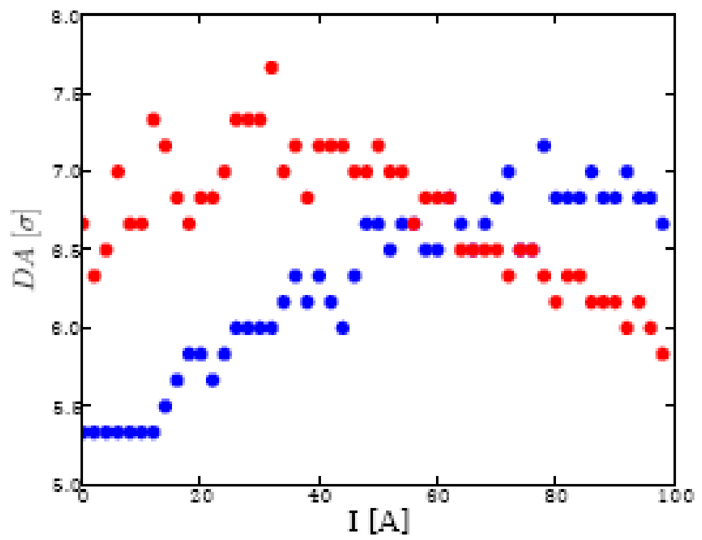
Electron Lenses for compensation of beam-beam effects, *V. Shiltsev, Fermilab*

2. *Head-on collisions: Foot-print compression. Two issues:*
   - *Demonstrate it can be implemented with sufficient accuracy and stability*
   - *Demonstrate it improves the luminosity lifetime: can that be done at Tevatron? Simulations ongoing for RHIC, soon for LHC (by LARP).*
3. *Long-range interactions: the wire compensation is simpler and cheaper but the e-lens offers additional and complementary functionalities: compensation of "small beam separations (<= 5 sig), PACMAN compensation.*

Wire compensation and Studies, *U. Dorda, U. of Wien & CERN*

1. ***Simulations:***

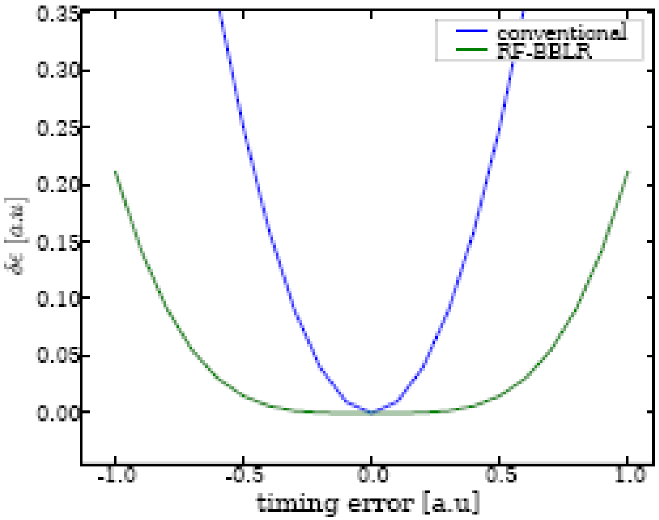
- ***The wire compensation increases the dynamic aperture from 5 to 7 sigma.***
- ***<u>Longer triplets</u> with same beam separation deteriorate the dynap by 2 sigma in spite of compensation***
- ***A DC system can improve the dynamics <u>both for nominal and extreme PACMAN</u> bunches***



Wire compensation and Studies, *U. Dorda, U. of Wien & CERN*

2. *Pulsed wire:*

   Going towards an RF solution for relaxed timing requirements, prototype under construction.

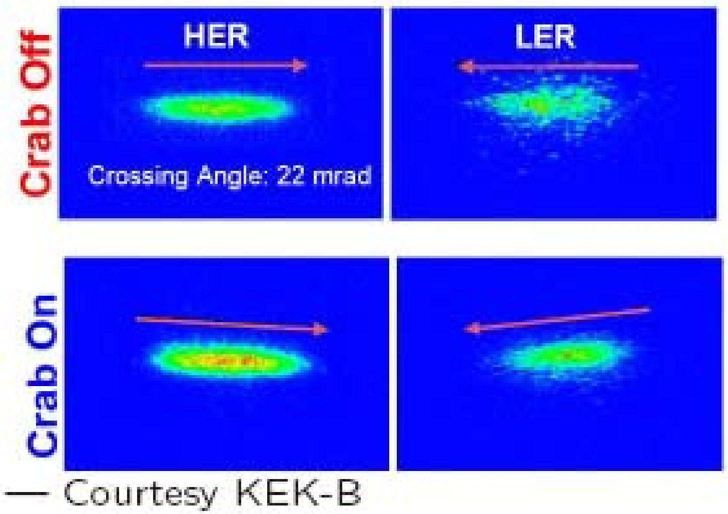


Wire compensation and Studies, *U. Dorda, U. of Wien & CERN*

2. *Machine experiments on long-range interactions simulated by a wire (summer 2007, SPS): 3 important results:*
   - *The simulations are not far from the experimental results (equally RHIC)*
   - *A RHIC observation is confirmed: the beam suffering long-range interactions becomes very sensitive to chromaticity.*
   - *The equivalent of 9 long-range interactions at a reduced distance (5 sigma) did not cause losses -> threshold mechanism or SPS accuracy insufficient?*

Crab Cavities & Emittance Growth Issues, *R. Calaga, BNL*

Crab cavities have become a reality in KEK-B:



For the LHC, the potential of small angle crabbing (0.3 to 0.6 mrad) is dramatic (*2 to *3 in luminosity)

Crab Cavities & Emittance Growth Issues, *R. Calaga, BNL*

<u>Global</u> crabbing (less cavities but perturbation all around the machine) appears attractive.

The orbit perturbation is up to <u>3 mm</u> and need to be assessed.

To prevent emittance growth, the amplitude and phase noise have to be tightly controlled: The requirement in amplitude noise can be fulfilled today with good margin. The phase noise requirement appears today to be feasible for the small angle considered. The noise spectrum is assumed white but in reality, it is not. This should give a safety margin.

Dedicated Workshop planned in 2008.

Effect of a few long-range encounters at a reduced distance, *N. Abreu, BNL*

- LHC with early separation scheme has between 1 and 3 LR encounters at 4-5σ;
  - Tevatron: 70 LR encounters at a mean separation of 9-10σ. Losses start for minimum separation smaller than 5-6σ;
  - SPS:
    - Wire experiments indicates that 2 LR interactions at 5σ can create losses that can not be tolerated at LHC;
    - Experiments with wire also show that for all 120 LR (I_{wire}=276 A) losses start at 8-9σ;
  - RHIC:
    - experiments with 1 LR (100 GeV/n) show onset of losses at 4σ;
    - BBLR experiment with 1-10 LR (I_{wire}=5-50 A) show onset of losses at 5-9σ (very sensitive to working point);

Effect of a few long-range encounters at a reduced distance, *N. Abreu, BNL*

Additional element: the RHIC machine was "especially" prepared to enhance the long-range beam-beam effect. Under nominal conditions, no effect is expected.

New data (see U. Dorda et al.) from 2 SPS experiments in summer 2007:

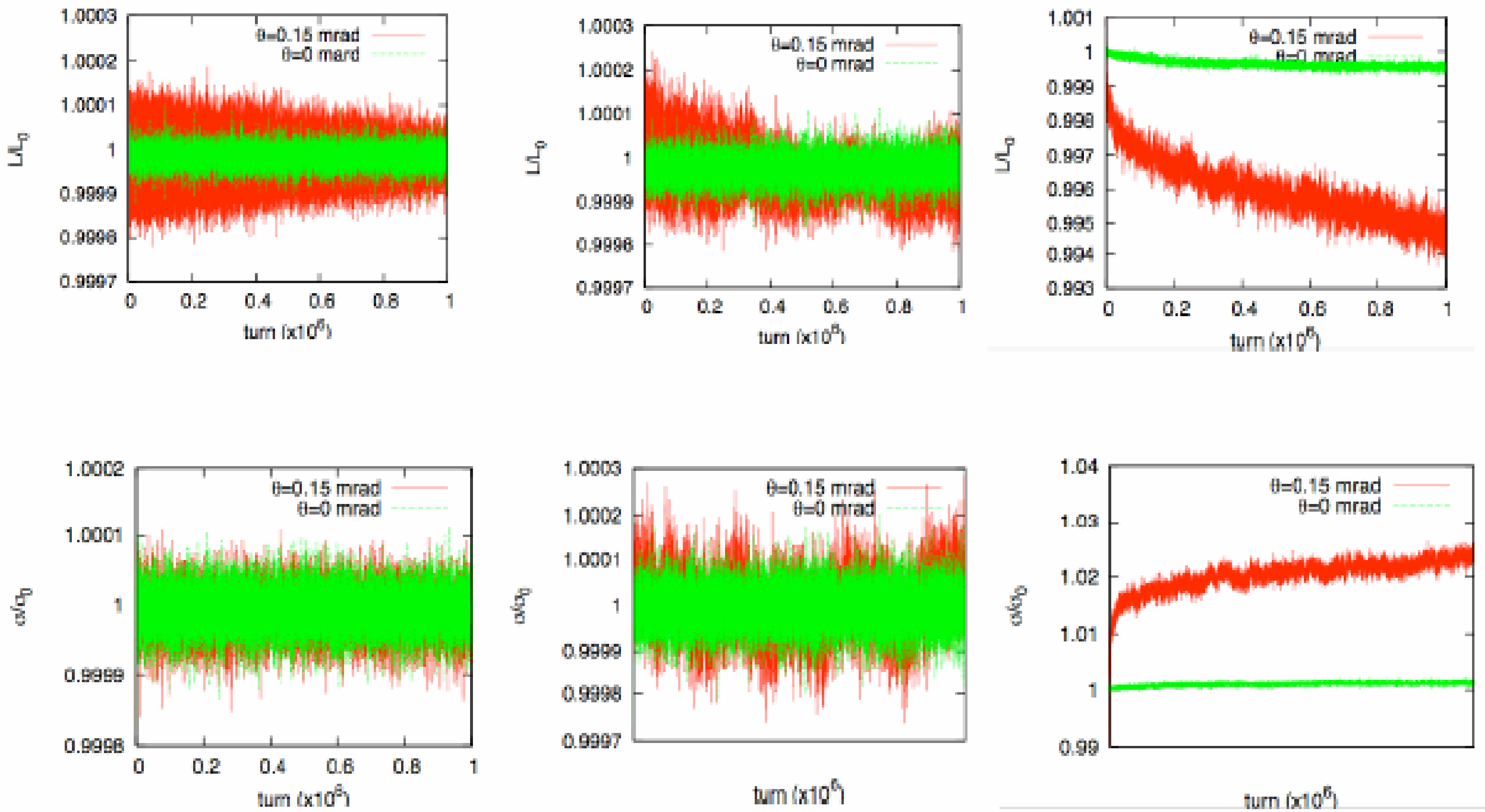
Wire excitation corresponding to 9 long-range encounters at 4.3 sigma and ultimate bunch charge did not show any observable beam loss.

The experiment reproduced at another energy seems to confirm.

Collisions with large Piwinski angle, *K. Ohmi, BNL*

1. ***Tracking:*** ***weak-strong for simplicity and reliability; careful treatment of Xing angle for simplecticity***
2. ***Xing angle & Beam-beam performance:*** ***for KEKB (electrons, high beam-beam parameter), the Xing angle does degrade the performance thru low-order resonance excitation. For perfect nominal LHC with only head-on, no degradation unless beam current increased by 8!***

$2xN_p$ $4xN_p$ $8xN_p$



No parasitic collision

Collisions with large Piwinski angle,
K. Ohmi, BNL

3. *Large Piwinski angle (Φ=2, FZ upgrade parameters):*
   - ***H-H: more tune spread & less resonances: OK***
   - ***H-V: OK without long-range but evidence of halo formation with long-range (more and stronger resonances influenced by phase shift between IP's)***
4. *These results sample the challenges to give hints. Systematic studies are needed.*

Tentative Conclusions

- *The e-lens has proven its reliability as abort gap kicker and its usefulness as <u>linear bunch-by-bunch tune shifter</u>. Results from Fermilab on its ability to compensate the HO are eagerly awaited. It has scope beyond beam-beam compensation.*
- *The wire compensation of the long-range beam-beam is more or less established. The efficiency of a dc system appears sufficient for both nominal & PACMAN bunches. <u>A promising research line is the RF wire excitation</u>. Alternatively, an e-lens L-R compensation would do the work.*
- *The KEK Crab cavity do rotate the bunches; the specific luminosity has improved; not yet the luminosity.*

Tentative Conclusions

- *The length of the triplet is a significant parameter for the long-range and favours short triplets. The crossing angle must be increased with the triplet length.*
- *The normalized Piwinski crossing angles contemplated for the Upgrade (LPA) do not seem to create a problem except perhaps with HV crossing (HH OK).*
- *Experiments have shown that a certain number of long-range encounters at a reduced distance can be tolerated. However, their exact number is not yet clear.. Another series of SPS and RHIC experiments would allow settling the issue, critical for the early separation scheme and luminosity leveling.*

Tentative Conclusions

1. *Perspectives*

   - ***For decades, the beam-beam effect in hadron colliders was mostly a "fact of life", limiting the performance of colliders and had to be accepted.***
   - ***Since a relatively short time, active unconventional systems have been invented AND (partially) implemented and experimented:***
     - ***Electron lens***
     - ***Long-range wire compensation***
     - ***Crab cavities***

Tentative Conclusions

1. *Perspectives (continued)*

- *The potential of these systems is largely above that of lattice or parameter optimization. They are therefore of direct interest for the LHC upgrade.*
- ***A complete demonstration of their suitability and power would be ideal but is very unlikely to be possible in practice given the extreme complexity and intrication of the beam-beam effectS in hadron machines. All efforts should be made in existing machines to gather more information. Enough seems available for decision making on implementation or further priority studies.***